Caterpillar Incorporated

New Coating Technology for Stronger, Longer Lasting Wear Parts

In the heavy manufacturing industry, strength, resilience, and reliability are vital characteristics in products. In the early 1990s, Caterpillar developed a research plan to apply functionally gradient material (FGM) coatings onto wear parts in a cost-effective manner so that the coated parts would last several times longer than parts currently available. By spraying a series of coatings designed for high adherence and wear and corrosion resistance onto common, low-cost steel substrates, one could affordably achieve durability and strength. The expected result would represent a breakthrough advancement for part strength, resilience, and reliability—an advance that would otherwise have taken the market more than 10 years to achieve incrementally. Although the potential of the proposed technology impressed Caterpillar engineers, cost pressure in the market would prevent the company from fully capturing the economic benefits of its proposed innovation.

Given the market structure for wear parts, Caterpillar could only slightly increase the cost of its parts, yet purchasers could use these stronger, more resilient parts for many more years than current parts. Therefore, Caterpillar and its five subcontractors (four companies and one university laboratory) submitted a proposal to the Advanced Technology Program (ATP). In 1994, ATP awarded Caterpillar $1.9 million in cost-shared funds to pursue FGM research. Through this three-year ATP project, the team developed new FGM systems that improve contact fatigue and wear and corrosion resistance of components such as gears, undercarriages for heavy earth-moving equipment, and rolls for steel mills. Because Caterpillar used the new technology to enhance several of its products, end users are now realizing the benefits of lower costs and higher quality products. In addition, several firms are marketing the technology for other applications within large mining operations and high-deposition thermal spraying.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 93-01-0055 were collected during October – December 2001.

Caterpillar Exceeds Customer Expectations

Gears, bearings, and other components that experience concentrated grinding and wear and tear have traditionally been coated using plating, case-hardening, and hard-facing coating technologies. The coatings were usually applied with a diffusion process and yielded a hardness gradient that did not affect elastic modulus (that is, the force that is applied to elongate material). But the processes were not perfect, and the components usually wore out. However, if coatings were developed that could be sprayed onto the surface of low-cost steel substrates, the resulting cost savings and product performance could be significant. Functionally gradient material (FGM) systems technology held this promise.

Caterpillar, a worldwide leader in the production of machinery and engines, believed it could reduce overall costs and deliver benefits to its customers through the use of FGM technology. The FGM systems would consist of ceramic and metal composites and graded materials designed for high adherence, wear resistance, increased strength, and corrosion

resistance. The use of new combinations of materials was expected to dramatically improve properties and performance over previous coating techniques.

Components that experience concentrated grinding and wear and tear have traditionally been coated using technologies that were not perfect, and the components usually wore out.

FGM has a continuously varying composition and/or microstructure from one boundary to another, and variations may result from gradients of ceramics and metals, metals with varying compositions, or nonmetallics in metals. Certain FGM systems, then, can improve contact fatigue and wear and corrosion resistance of components such as gears, undercarriages for heavy earth-moving equipment, and rolls for steel mills.

Caterpillar's proposed innovations would increase the life span of the company's parts several times over. Nevertheless, the market would allow the company to only slightly increase the price of parts. Customers and end users, therefore, would receive the bulk of the economic benefits flowing from a successful FGM research project.

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Rather than abandon the promising technology, Caterpillar established a team to research and develop FGM systems technology and submitted a proposal to ATP in 1994. This research team consisted of Hoeganeas Inc.; Department of Materials Science and Engineering, State University of New York at Stony Brook (SUNY); IBIS Associates, Inc.; Chaparral Steel Company; and St. Louis Metallizing Company.

Caterpillar Defines Specific Project Objectives

When Caterpillar began its ATP-funded project, the goals of the project were explicit; however, as the project got under way, the goals expanded.

The initial goals were to:

- Develop the materials and process technology base necessary to produce new FGM systems to improve the contact fatigue and wear and corrosion resistance of components such as gears for equipment, undercarriages for heavy earth-moving equipment, rolls for steel mills, and wear components for mining equipment
- Eliminate chrome plating to ease environmental concerns

Specific targets set to achieve these goals included:

- Replacing chrome plating on hydraulic cylinder rods, with similar performance and cost, while minimizing environmental concerns.
- Creating abrasive wear applications for track-type tractor undercarriages (track rollers) to achieve a threefold increase in wear resistance at only twice the current materials cost.
- Developing high contact stress gear applications used in track-type tractor final drives with a tenfold increase in contact fatigue life at only 1.75 times the current gear cost.
- Generating stainless clad steel products at a reduced cost.
- Developing a less costly, high-deposition spray process for use in spraying large components. Cost savings would depend on overall labor costs, because the new FGM deposition process would be 10 to 20 times faster than older processes.

As the project progressed, the targets expanded to include the following goals:

- Design and develop 1-mm- to 10-mm-thick FGM coating for chrome plate replacement, abrasive wear resistance (track roller), and high contact fatigue resistance (gear)
- Identify powder compositions for producing cost-effective FGM coating

- Develop a process to incorporate hard particles in powder form
- Determine optimum powder production processes and particle size for water stabilized plasma (WSP) spray systems
- Identify high-velocity oxygen-fuel (HVOF) coating technology for chrome-plate replacement

ATP Project Team Accomplishes Goals

The ATP-funded project resulted in the following major accomplishments:

- Cost-effective processing technology identified to produce FGMs, coatings that gradually change in composition throughout their thickness and may be deposited on steel and other substrates
- Cost-effective consolidation techniques demonstrated for these FGM materials
- WSP technology infrastructure established for limited production of FGM components
- HVOF coating technology identified for chrome-plate replacement
- Powder feed stock materials identified for spraying and spray deposit consolidation technologies to enhance the properties and structures of the sprayed FGM

Originally, three spray processes were evaluated for use in spraying FGM technologies. These processes included WSP technology, axial-injected spray technology, and HVOF spray technology.

The development goals were to establish the powder distribution and spray parameters required for high deposition efficiencies (greater than 80 percent) and high spray rates (greater than 150 lb/hour) using metal powders. A WSP system and an axial plasma spray system at SUNY were used to evaluate the capabilities of these spray technologies. In addition, HVOF spray systems at Caterpillar were used to evaluate coatings produced.

Results for the axial plasma and HVOF systems indicated that, although the current generation of spray guns does have high deposition efficiencies, they are limited in their spray rates to 10 to 30 lb/hour, which is the same as other gas-stabilized plasma torches. This limitation requires additional systems with capital and maintenance costs that are higher than the WSP system, which is capable of spraying metals at 200 lb/hour at deposition efficiencies of 80 percent. The spray coatings were developed with the required density and corrosion resistance to replace chrome plating.

The spray-coating technology developed during the course of the ATP-funded project was rolled out in the late 1990s in place of chrome plating for repair operations at Caterpillar dealers. It also is being considered for implementation in hydraulic cylinder rod production at Caterpillar to replace existing chrome plate operations.

Caterpillar Achieves Wide-Ranging and Sustained Technical and Business Achievements

The benefits resulting from this ATP project are considerable and ever increasing, as demonstrated by the current activities of the participants involved. For example, St. Louis Metallizing and Caterpillar have entered into a joint development agreement to further market the WSP technology, as well as other thermal spray technologies for applications outside those developed for Caterpillar. St. Louis Metallizing is pursuing marketing and production campaigns for HVOF and FGM coatings developed during the project. St. Louis Metallizing also is working with Ford Motor Company to market the spray forming of stamping dies, and it performed work with the WSP 500 as a lower cost way to spray large components.

End users in the marketplace are enjoying sturdier, more durable parts at lower costs, at least 10 years earlier than would have been possible without the ATP-funded project.

In 1998, Caterpillar and St. Louis Metallizing entered into a five-year joint-venture blanket agreement that included sharing knowledge and people between the two companies. In 2001, Caterpillar entered into

alliances with Oak Ridge National Laboratory and Albany Laboratories to continue FGM developments started during this project. Caterpillar has contracted with an independent power producer to develop a new generation of lower power WSP systems to satisfy Caterpillar's specific needs for economical spray technologies at spray rates that are lower than the original WSP system.

Conclusion

Caterpillar engineers developed new manufacturing techniques that increased the life of wear parts between threefold and tenfold. Given the cost pressures placed on Caterpillar by the competitive marketplace, the cost of the longer lived parts would have to remain relatively low, and end users would capture most of the economic benefits of the new products. To develop the technology, Caterpillar teamed with several subcontractors and then applied for and received an ATP award of $1.9 million. The project achieved its technical goals, and end users in the marketplace are enjoying sturdier, more durable parts at lower costs, at least 10 years earlier than would have been possible without the ATP-funded project.

PROJECT HIGHLIGHTS
Caterpillar Incorporated

Project Title: New Coating Technology for Stronger, Longer Lasting Wear Parts (Functionally Gradient Materials: Synthesis, Process, and Performance)

Project: To develop new, advanced materials and processing techniques for applying high-performance coatings with continually varying composition on low-cost substrates.

Duration: 2/1/1994-1/31/1997
ATP Number: 93-01-0055

Funding (in thousands):**

ATP Final Cost	$ 1,995	56%
Participant Final Cost	1,556	44%
Total	$3,551	

Accomplishments: The Caterpillar team achieved its research and development goal of producing new FGM systems and realized the following achievements:

- Developed cost-effective processing technology to produce FGMs
- Designed and built a WSP spray system for FGMs
- Replaced previous chrome-plating technologies with environmentally friendly FGMs

The processes enabled goods such as tractor gears to last 10 times longer than before the ATP-funded project, without a concomitant increase in cost. In fact, the increase in cost was less than twofold. Tractor undercarriages, for example, now last three times longer, with only a twofold increase in cost. The tractor owners, operators, and purchasers are enjoying longer lasting parts, lower capital equipment costs, and more efficient use of their resources. Caterpillar received the following six patents for technologies resulting from ATP's cost-shared funding:

- "Process for Reducing Oxygen Content in Thermally Sprayed Metal Coatings" (No. 5,707,694: filed October 3, 1996, granted January 13, 1998)
- "Process for Reducing Oxygen Content in Thermally Sprayed Metal Coatings" (No. 5,736,200: filed October 3, 1996, granted April 7, 1998)
- "Carbon Coated Metal Powder Depositable by Thermal Spray Techniques" (No. 5, 882,801: filed October 3, 1996, granted March 16, 1999)
- "Process for improving fatigue resistance of a component by tailoringcompressive residual stress profile, and article" (No. 5,841,033: filed December 18, 1996; granted November 24, 1998)
- "Process for applying a functional gradient material coating to a component for improved performance" (No. 6,048,586: filed April 8, 1998; granted April 11, 2000)
- "Component having a functionally graded material coating for improved performance" (No. 6,087,022: filed April 8, 1998; granted July 11, 2000)

Commercialization Status: Commercialization is in progress, and products enhanced with FGMs are currently being sold. Products include chrome replacement processes for large mining cylinder rods by Chaparral Steel Company and high-deposition thermal spraying using WSP technology by St. Louis Metallizing. Companies that are using the enhanced Caterpillar equipment are realizing the benefits of lower costs and higher quality products. In addition, other consortium members are leveraging the HVOF technology in their efforts to improve hardness for track rollers, other undercarriage components of heavy machinery, and power transmission gears. In addition, other applications resulting from the ATP project include stainless clad sucker rods and structural steel, track bushings, steel and paper mill rolls, clad rebar, and other structural materials.

Outlook: The use of this technology is expected to spread throughout the industry, decreasing the costs and improving the quality of several products. As a result of this ATP project, alliances and joint ventures have been formed in an effort to continue exploiting the potential of this newly developed technology in the heavy equipment and other industries. The end result of cheaper and more durable parts saves end users significant repair and replacement costs. The outlook for this technology is good.

Composite Performance Score: * * *

** As of December 9, 1997, large single applicant firms are required to pay 60% of all ATP project costs. Prior to this date, single applicant firms, regardless of size, were required to pay indirect costs.

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Subcontractors:

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- Department of Materials Science and Engineering, State University of New York at Stony Brook (SUNY)
- IBIS Associates, Inc.
- Chaparral Steel Company
- St. Louis Metallizing Company

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